



# Ground Water Currents

Developments in innovative ground water treatment

## Hydrodynamic Cavitation Oxidation Destroys Organics

By Richard Eilers, Risk Reduction Engineering Laboratory

The CAV-OX<sup>®</sup> technology destroys organic contaminants (including chlorinated hydrocarbons) in water. The process uses hydrogen peroxide, hydrodynamic cavitation and ultraviolet (UV) radiation to photolyze and oxidize organic compounds present in water at parts per million to nondetectable levels. Ideally, the end products of the process are water, carbon dioxide, halides and—in some cases—organic acids. The CAV-OX<sup>®</sup> technology was evaluated at a SITE (Superfund Innovative Technology Evaluation) demonstration at Edwards Air Force Base Site 16 in California. Ground Water at Site 16 is contaminated with volatile organic compounds (VOCs), primarily trichloroethene (TCE) and BTEX compounds (benzene, toluene, ethylbenzene and xylenes).

Almost 8,500 gallons of contaminated ground water were treated during a two-week period. Initial contaminant concentrations were 1,475 to 2,000 parts per billion (ppb) TCE, 240 to 500 ppb benzene, 8 to 11 ppb toluene and up to 100 ppb xylene. The CAV-OX<sup>®</sup> systems achieved removal efficiencies of up to >99.9% for TCE and BTEX compounds.

The major components of the CAV-OX<sup>®</sup> system are the cavitation chamber, UV

reactor and control panel unit. Prior to entry into the cavitation chamber, ground water was pumped from three monitoring wells into a 7,500 gallon equalization tank. A bladder tank was used as the equalization tank to minimize variability in influent characteristics. From the equalization tank, the water was transferred to an influent holding tank, where hydrogen peroxide was added. The water was then pumped to the cavitation chamber.

Cavitation occurs when a liquid undergoes a dynamic pressure reduction while under constant temperature. The hydrodynamic cavitation is induced through the shape of the cavitation chamber, which causes pressure variations in a flowing liquid. A pressure reduction causes gas bubbles to suddenly develop, grow and then collapse. This cavitation decomposes water into extremely reactive hydrogen atoms and hydroxyl radicals, which recombine to form hydrogen peroxide and molecular hydrogen, which help oxidize the organic compounds. Flow can be recycled through the cavitation chamber to control the hydraulic retention time before it is transferred to the UV reactor.

The UV reactor houses low-pressure mercury-vapor lamps that generate UV

radiation, which further oxidize the organic compounds. Each lamp is housed in a UV-transmissive quartz tube, which is mounted entirely within the UV reactor. Hydroxyl and hydroperoxyl radicals are produced by direct photolysis of hydrogen peroxide at UV wavelengths. During the SITE demonstration, no scaling of the quartz tubes was observed. Treated ground water was stored in an effluent storage tank prior to disposal.

Magnum Water Technology manufactures both low-energy and high-energy UV systems, both of which were evaluated during the SITE demonstration. The low-energy CAV-OX<sup>®</sup> I system contains six 60-watt lamps per reactor. The high-energy CAV-OX<sup>®</sup> II system contains two UV reactors with one UV lamp each and can operate at 2.5, 5, 7.5 or 10 kilowatts (kW). Flow capacity is estimated to be less than 3 gallons per minute (gpm) for the low-energy system and less than 5 gpm for the high-energy system. Three configura-

tions of the CAV-OX<sup>®</sup> technology were demonstrated during the SITE evaluation: the CAV-OX<sup>®</sup> I system operating at 360 watts and the CAV-OX<sup>®</sup> II system operating at both 5 kW and 10 kW. The demonstration consisted of 15 runs for each configuration of the CAV-OX<sup>®</sup> technology. The high-energy system was first operated with the UV reactor at 10 kW and then at 5 kW. Ground water samples were collected before and after treatment during each run to determine the technology's effectiveness in removing VOCs from ground water. The principal operating parameters—hydrogen peroxide dose, pH and flow rate—were varied during the demonstration to evaluate the technology's performance under different conditions.

For more information, contact Richard Eilers at EPA's Risk Reduction Engineering Laboratory at 513-569-7809. An "Applications Analysis Report and a Technology Evaluation Report" will be available in the summer of 1994.

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## Biosparging Documented in Fuel Remediation Study

By Don Campbell, Robert S. Kerr Environmental Research Laboratory

EPA's Robert S. Kerr Environmental Research Laboratory (RSKERL), through a three-year research study, has documented subsurface aeration (biosparging) remediation of an aviation gasoline spill at the U.S. Coast Guard Air Station site in Traverse City, Michigan. This case study has shown that fuel volatilization by aeration and vadose zone biodegradation of vapors is a convenient way to remove dissolved hydrocarbons from ground water in situations where large amounts of spilled fuel have moved downward through a porous

vadose zone and formed a plume in the aquifer. Sparge aeration can cleanse the water of fuel hydrocarbons to meet ground water quality standards. However, sparge cleansing of the plume water is a short-term solution unless there is further remediation of the aquifer. This study found that complete remediation of contaminants was prevented by fuel globules trapped in capillary pores of sand granules that protected them from the sparge aeration. These oily globules can recharge and maintain the contaminant plume once sparging ceases.

At the Traverse City site, about 36,000 gallons of gasoline had spilled in 1969 as a result of a flange failure of an underground transfer line. During the next 20 years a plume 1,200 feet long down gradient was formed. The water table is at a depth of approximately 15 feet with an oily phase smear of almost five feet, due to fluctuations in water depth resulting from climatic changes. During the study period about one-third of the smear zone was in the vadose zone and two-thirds were at or below the water table. Both the aquifer and the

vadose zone were composed of relatively uniform beach sand.

Prior to the field-scale study, an eight-month bioventing pilot-scale demonstration was conducted. At its completion in 1991, the system's performance showed that 99% of the fuel hydrocarbons in the vadose zone were removed, with only minimal surface emissions. Upon completion of the pilot study, aeration wells were installed in the same plot to a depth of 10 feet below the water table. The rate of aeration was the same as for the pilot-scale (SEE BIOSPARGING, PAGE 3)

## Surfactant Flushing Research to Remove Organic Liquids from Aquifers

By Linda M. Abriola and Kurt D. Pennell, University of Michigan

Organic liquids, such as gasoline and industrial solvents, are a major source of ground water contamination throughout the United States. Through the Great Lakes/Mid-Atlantic Hazardous Substances Research Center, researchers at the University of Michigan have combined detailed laboratory experiments with the development of mathematical models to investigate the potential usefulness of surfactant flushing as an aquifer-remediation

technology. The specific objectives of this research were to: (1) screen and select surfactants that will enhance the solubility of organic liquids in water; (2) measure the solubility of dodecane and tetrachloroethylene (PCE) in aqueous surfactant solutions; (3) quantify the ability of selected surfactants to recover entrapped dodecane from soil columns; and (4) develop and evaluate numerical models capable of predicting surfactant-enhanced solubilization and

mobilization of organic liquids in ground water systems.

First, commercially available surfactants were screened based on their toxicity, biodegradability, molecular structure and potential to solubilize organic compounds. The screening process led to the selection of three nonionic surfactants for experimental testing with two organic liquids, dodecane and PCE, as model compounds. The researchers found that adding these surfactants to water

increased the aqueous solubility of PCE and dodecane by 200 times and one million times, respectively. The large enhancement in solubility results from the incorporation or partitioning of organic compounds within surfactant micelles (colloidal-size clusters). Surfactant molecules aggregate to form micelles above a specific concentration, the critical micelle concentration (CMC). The micelles possess a (SEE SURFACTANT FLUSHING, PAGE 4)

## Compilation of Ground-Water Models

EPA's Robert S. Kerr Environmental Research Laboratory has published a report, "Compilation of Ground-Water Models" (Document No. EPA/600/R-93/118). This report is a review of ground water models and is based on information gathered by the International Ground Water Modelling Center (IGWMC) under a research and technology transfer cooperative agreement with the EPA. The IGWMC was established as an international clearinghouse and technology transfer center for ground water modelling.

Ground water modelling, as a computer-based methodology for mathematical analysis, is a tool for investigating and managing the mechanisms and controls of ground water systems. Models are playing an important role in the determination of the physical and economical effects of

proposed ground water protection policy alternatives and thus the protection of human and ecological health. Computer models are important tools in the screening of alternative remediation technologies and strategies in cleaning up ground water systems polluted in the (recent) past, in the sound design of ground water resource development schemes for water supply and for other land use modifications affecting ground water systems.

The model selection process for appropriate computer codes is a vital step to conducting these investigative and management alternatives for ground water systems. To be able to select a computer code appropriate for the type of analysis to be performed, ground water modelers need to have an overview of available computer codes and their

characteristics. These modelling codes are used for the evaluation of policies, actions and designs that may affect such systems. This report presents the methodology used by the IGWMC to classify, evaluate and manage descriptive information regarding ground water modelling codes for the purpose of model selection. Furthermore, the report provides an overview of available ground water modelling codes and their major characteristics. A section is included that defines ground water modelling, presents the classification approach taken by the IGWMC and discusses different types of models and the mathematical approaches invoked for developing the models. Separate sections discuss and review the different categories of ground water models: flow models, transport models, chemical reaction

models, stochastic models, models for fractured rock and ground water management models.

The appendices include a listing and description from the IGWMC Model Annotation Search and Retrieval System (MARS) of selected models from each category. Currently this MARS database is installed on a micro-computer operating under MS-DOS. Detailed information on the reviewed models is presented in a series of tables, preceded by an introduction on model classification and principal characteristics of the described models.

The report can be ordered from EPA's Center for Environmental Research Information at 513-569-7562. Please refer to Document No. EPA/600/R-93/118 when ordering.

## Biosparging, from page 2

bioventing—an air flow pattern upward that enabled the air to remain below ground for approximately 24 hours. Plume water initially containing several hundred micrograms per liter (ug/l) of BTEX compounds (benzene, toluene, ethylbenzene and xylenes) was cleansed to <1 ug/l.

After one year of operation, and again after two years, replicate vertical profile core

samples were collected from the sparged plot and from an adjacent non-sparged control in the plume. Considerable variations between replicated profiles for fuel carbon concentrations were detected. Averaged values for total fuel carbon of replicates showed that non-sparged control samples decreased by 10% while sparged replicates showed a 42% decrease. Most of the sparged decrease occurred during the first year. The ability of the system to completely

eliminate contaminants was restricted because of fuel globules trapped in capillary pores of sand granules which protected them from the sparge aeration.

For more information, call Don Kampbell at RSKERL at 405-436-8564. A history of the first year of work has already been published; the reference is: Kampbell, D. H., C. J. Griffin and F. A. Blaha, "Comparison of Bioventing and Air Sparging for In-Situ Bioremediation of Fuels,"

*Proceedings of Symposium on Bioremediation of Hazardous Wastes: Research, Development, and Field Evaluations, Dallas, Texas, 1993, pp. 61-65 (Document No. EPA/600/R-93/054)* and can be ordered from EPA's Center for Environmental Research Information at 513-569-7562. A publication on the full study is anticipated for the Fall of 1994.

## Surfactant Flushing, from page 2

lipophilic (attracted to or soluble in oils) core surrounded by a hydrophilic (attracted to or soluble in water) mantle. When the concentration of surfactant exceeds the CMC, organic compounds dissolve within the lipophilic core of surfactant micelles.

The most promising surfactant tested, polyoxyethylene (20) sorbitan monooleate (trade name Tween 80 or Witconol 2722), was used in the soil-column experiments. This is a food-grade surfactant commonly used in dietary supplements, flavoring agents, whipped toppings and shortenings. Dodecane was used as the model organic compound.

Prior to surfactant flushing, dodecane was entrapped in

water-saturated soil columns packed with a uniform sand. After the introduction of a 4% surfactant solution, the concentration of dodecane exiting the column increased dramatically. Removal of 10% of the residual dodecane required 0.7 liters of surfactant solution. Comparable recovery of dodecane without surfactant would have required approximately 130,000 liters of water.

Although high, the concentrations of dodecane measured in the column effluent were seven times less than those measured in batch experiments. These results imply that the equilibrium solubility of dodecane was not reached within the soil column. Subsequent column experiments conducted at several flow rates confirmed

the existence of rate-limited, rather than instantaneous, solubilization of residual dodecane. Numerical models were then developed which coupled surfactant transport with the solubilization of residual organic liquids. The models were used to interpret laboratory experiments, evaluate alternative remediation strategies and investigate the factors which influence the solubilization and mobilization of organic liquids at the field scale. Using these models, HSRC researchers explored optimal surfactant strategies, based on flow rate, flushing time and volume of surfactant solution required to remove residual dodecane from soil columns.

This research demonstrates the ability of surfactants to

enhance the solubility of organic liquids and to promote recovery of entrapped organic liquids from soil columns. Model simulations were shown to be valuable tools in interpreting data and evaluating alternative pumping strategies. The results of these projects provide a basis for further development of surfactant flushing as an aquifer remediation technology. Ongoing research efforts focus on processes influencing the solubilization and mobilization of PCE entrapped within several aquifer materials.

For more information, contact Linda Abriola at the University of Michigan (313-764-9406).

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